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Foraging behavior of *Chrysoperla carnea* and *Hyperaspis vinciguerra* fed on *Phenacoccus solenopsis*

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Abstract

Searching rate, mutual interference, and killing power were studied for two predator species, *Chrysoperla carnea* (Stephens) (Neuroptera: Chrysopidae) and *Hyperaspis vinciguerrae* Capra (Coleoptera: Coccinellidae) fed on the cotton mealybug, *Phenacoccus solenopsis* Tinsley under laboratory conditions of 27 ± 2 °C and $70 \pm 5\%$ RH. The predator *C. carnea* showed relatively higher searching rate on the prey nymphs in comparison with its adults. By increasing predator density, the searching rate on prey adults was slightly decreased in comparison with prey nymphs. Mutual interference value on adults was lower than on nymphs. On another hand, Killing power (as K-value) of *C. carnea* and *H. vinciguerra* was generally higher on *P. solenopsis* nymphs in comparison with adults. Generally, *C. carnea* larvae were more effective on the nymphs and adults of cotton mealybug, *P. solenopsis* than *H. vinciguerra* adults. So, the predator *C. carnea* can play an effective role in controlling *P. solenopsis* population when the predator: prey ratio is about 1: 10. Accordingly, in augmentative biological programs of *P. solenopsis* by predators, predator: prey ratio has to be accurately estimated to minimize the negative effects of interference on foraging efficiency.

Keywords: searching rate, mutual interference, killing power, predators, mealybug

Introduction

Cotton mealybug, *Phenacoccus solenopsis* Tinsley (Hemiptera: Pseudococcidae) is a serious sucking pest of cotton vegetables, ornamental plants and fruit trees worldwide and is known to be cryptic in nature ^[1]. It was described originally from the U.S. in 1898 and it remained there until 1992. Later it was reported in Central America, the Caribbean and Ecuador. Since 2005, this newly world species (*P. solenopsis*) has emerged as serious pest of cotton in Pakistan and India, and now it is a serious threat to cotton in China. It has been reported from 173 species in 45 plant families and from 26 countries in different ecological zones ^[2]. According to Fallahzadeh *et al.* (2014) ^[3], most *P. solenopsis* hosts belonging to families Solanaceae, Malvaceae and Cucurbitaceae, representing for 48% of the reported host plants. In Egypt, cotton mealybug was recorded firstly on weeds ^[4] and subsequently on tomato plants as a new insect pest ^[5].

Cotton mealybug causes damage by depleting the sap from all plant parts such as feeders on roots, root crowns, stems, twigs, leaves, flowers, and fruits. They can occasionally inject toxins, transmit viruses or excrete large amounts of honeydew stimulating the growth of sooty mould ^[6]. Injured plants have discolored, wilted, produce fewer bolls of a smaller size and the deformed leaves turn yellow then dry up and eventually fall off ^[1, 7-9].

Biological control involving predators played an important role in suppressing mealybug pests of economically important crops. Several previous studies of coccinellid predators have dealt with functional and numerical responses ^[10-16]. According to Hassel & Varley (1969) ^[17], Hassel (1971) ^[18] and Delong & Vasseur (2011) ^[19], mutual interference is known as the interference competition which occurs when access to resources is negatively affected by the presence of other individuals. Searching behavior is the active movement by which insects seek food ^[20]. On the other hand, Abd El-Kareim (1998) ^[21] defined the killing power as a specific mortality caused by factors such as predation, parasitism, and natural mortality.

Coccinellids and chrysopids are thought to be major predators of *P. solenopsis* ^[22, 23]. Abd El-Kareim (1998, 2002) ^[21, 24], Bayoumy & Michaud (2012) ^[25] and Al-Doghairi *et al.* (2014) ^[16] studied searching rate, mutual interference, and killing power of the *Coccinella undecimpunctata* L., *Chilocorus bipustulatus* (L.), *Exochomus flavipes* (Thunb), *Nephus*

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inclusens (Kirsch) and *Hippodamia tredecimpunctata* L.

There is a lack of information about foraging behavior of *C. carnea* and *H. vinciguerra* when fed on *P. solenopsis*. Therefore, the present study aimed to evaluate the searching rate, mutual interference, and killing power of these predators when fed on the cotton mealybug, *P. solenopsis* in the laboratory.

3. Materials and Methods

3.1. Predator cultures

Larvae of *C. carnea* were obtained from the Bio-Control Laboratory of Plant Protection Institute, Agricultural Research Center, Ministry of Agriculture, Egypt. They were maintained on *P. solenopsis* at $27 \pm 2^\circ\text{C}$, $65 \pm 5\%$ RH and 16:8 L:D. With respect to the pitchfork lady beetle, *H. vinciguerra*, approximately 100 adults of were collected using a sweep net from eggplant field in Mansoura district, Egypt. Under laboratory conditions of $27 \pm 2^\circ\text{C}$, $65 \pm 5\%$ RH and 16:8 L:D, the collected individuals of each species were kept in plastic chimney cages (30 cm in diameter and 25 cm height) and provided daily with potato tubers that were highly infested with the cotton mealybug, *P. solenopsis* a food source. Twenty pairs each *C. carnea* and *H. vinciguerra* were sexed. Mated females were isolated individually in small plastic cages (5 cm diameter and 4 cm height) containing the same prey and covered with pieces of thin fabric fixed with rubbers. These cages were examined daily and the numbers of eggs that had been deposited were recorded. Eggs were transferred to new small cages and their development was daily checked. Hatching larvae were provided with *P. solenopsis* as food throughout the experiments.

3.2. Foraging behavior

Searching rate and mutual interference values for *C. carnea* and *H. vinciguerra* were examined using the nymphs and adults of *P. solenopsis* under laboratory conditions. Newly molted predator larvae of *C. carnea* (as 3rd instar) and newly eclosed adults of *H. vinciguerra* were starved for 24 hours before experiments. To evaluate searching rate and mutual interference values, five densities (1, 2, 5, 7 and 9 individuals) of each predator were tested in response to both prey stages. Infested potato tubers with *P. solenopsis* were used. Ten prey individuals (of 3rd instar nymphs or adults) were introduced into the previously mentioned small plastic cages containing the starved predator individuals. After two days, treatments were examined and the numbers of remaining live mealybugs were counted. Experiments were replicated ten times for each predator density. The formula of Varley *et al.* (1973) [26] was used to estimate predator searching rate:

$$a_t = 1/P \log_e (N/N - N_a);$$

where, a is the searching rate, t is the time of exposure (2 days), P is the predator density, N is the prey density, and N_a is the number of prey consumed.

Because searching rate is not constant and there is mutual interference among predators, the model of Hassel & Varley (1969) [17] was used:

$$a_t = QP^{-m};$$

where, a is the searching rate, t is the time of exposure (2 days), Q is the quest constant (searching rate of one predator individual), m is the mutual interference constant (slope of

regression of $\log a_t$ divided by $\log P$), and P is the predator density. Thus, the equation becomes linear as follows:

$$\log a_t = \log Q - m \log P;$$

3.3. Killing power

The killing power (K-value) for *C. carnea* 3rd instar larvae and *H. vinciguerra* adults was examined at ten predator: prey ratios for the two prey stages. In the previously mentioned small plastic cages, ratios of 1:10, 1:20, 1:30, 1:40, 1:50, 1:60, 1:70, 1:80, 1:90 and 1:100 (predator: prey) were evaluated. Infested potato tubers with *P. solenopsis* were used. After two days, treatments were examined and the numbers of remaining live mealybugs were counted. Experiments were replicated ten times for each predator: prey ratio. The K-value was calculated according to Varley *et al.* (1973) [26]:

$$K\text{-value} = \log_e (N/N - N_a);$$

where, N is the prey density and N_a is the number of prey consumed.

4. Results

4.1. The green lacewing, *C. carnea*

Searching rate, mutual interference and killing power (as K-value) of *C. carnea* larvae on the adults and nymphs of the cotton mealybug, *P. solenopsis* were studied under laboratory conditions. The searching rate of *C. carnea* at different larval densities is illustrated in Figure (1). The predator showing relatively higher searching rate (- 0.555) on the prey nymphs in comparison with its adults (- 0.670). By increasing predator density, the searching rate on prey adults was slightly decreased in comparison with prey nymphs. Mutual interference value on adults was (0.283) lower than on nymphs (0.370). Therefore, by increasing predator density, searching rate per larva was obviously decreased on prey nymphs in comparison with adults (Figure, 1).

According to the obtained data, the relationship between the searching rate "Log a" and predator density "Log P" can be represented by the following submodels:

On prey adults: $\log a = -0.670 - 0.283 \log P$.

On prey nymphs: $\log a = -0.555 - 0.370 \log P$.

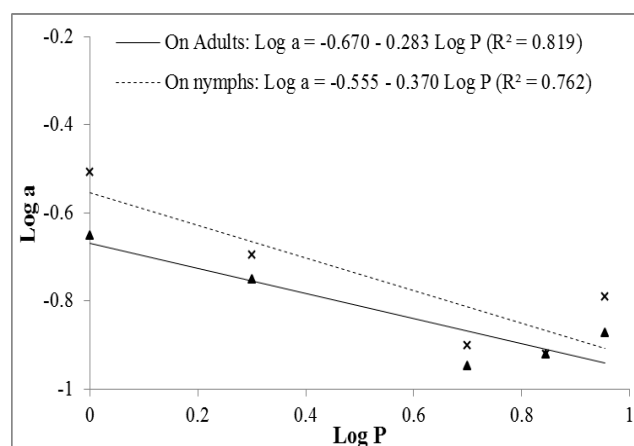


Fig 1: Relationship between predator density (Log P) and searching rate (Log a) of *C. carnea* (as 3rd instar larvae) in response to adults and 3rd instar nymphs of the cotton mealybug, *P. solenopsis*.

Figure (2) shows that K-values for *C. carnea* at the 1: 10 (as predator: prey ratio) reached 1.002 and 1.100 for on prey

adults and nymphs, respectively, and decreased in the rest of predator: prey ratios (as increasing the prey numbers). The lowest K-value was recorded in the ratio of 1: 80; where, k-values on adults and nymphs were 0.299 and 0.431, respectively.

On another hand, killing power of *C. carnea* was generally higher on *P. solenopsis* nymphs in comparison with adults (Figure, 2). However, the general mean of K-values in the entire studied predator: prey ratios reached 0.546 on nymphs and 0.432 on adults.

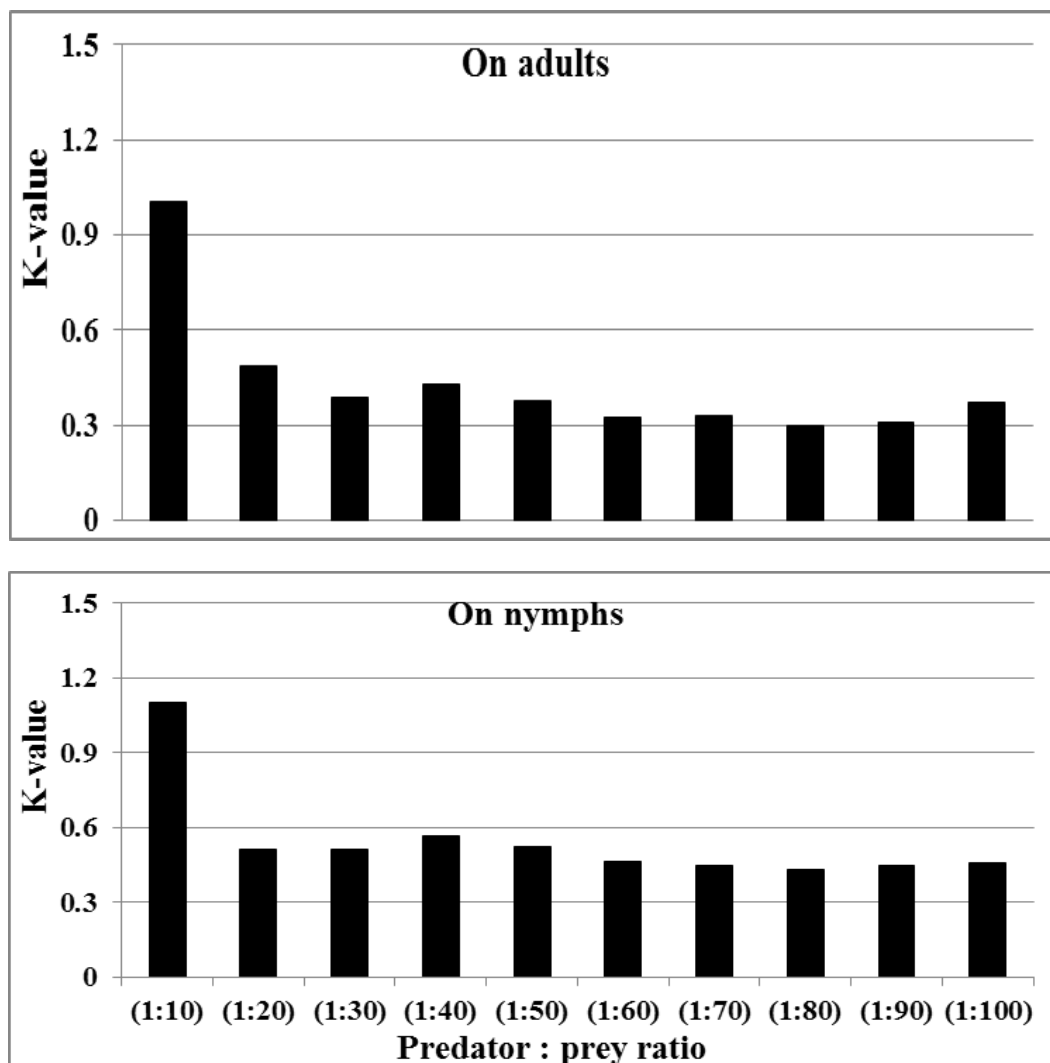


Fig 2: K-value of *C. carnea* (as 3rd instar larvae) at different predator: prey ratios on adults and 3rd instar nymphs of the cotton mealybug, *P. Solenopsis*.

4.2. The pitchfork lady beetle, *H. vinciguerra* :

As it previously obtained in the case of *C. carnea* larvae, adults of *H. vinciguerra* showed relatively higher searching rate on *P. solenopsis* nymphs in comparison with prey adults (Figure, 3). However, the searching rates on nymphs and adults of the prey reached -0.444 and -0.619, respectively. The searching rate decreased by increasing predator density; where, this decreasing was relatively higher on prey nymph in comparison with adults. Mutual interference values on adults and nymphs of prey were 0.332 and 431. So, it could be

reported that, searching rate of *H. vinciguerra* adults decreased by increasing predator density, and this decrease was obviously on prey nymphs more than on prey adults.

The relationship between the searching rate "Log a" of *H. vinciguerra* adults and its density "Log P" could be represented by the following submodels:

On prey adults: $\text{Log } a = -0.619 - 0.332 \text{ Log } P$.

On prey nymphs: $\text{Log } a = -0.444 - 0.431 \text{ Log } p$.

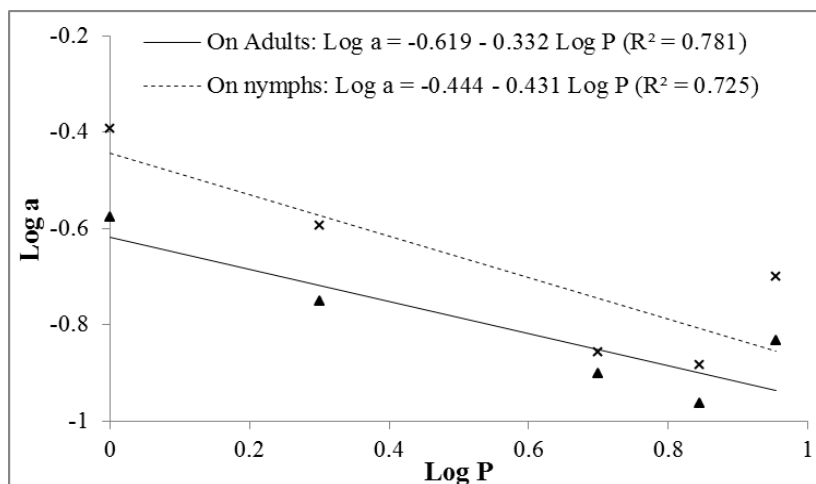


Fig 3: Relationship between predator density (Log P) and searching rate (Log a) of *H. vinciguerra* (as adults) in response to adults and 3rd instar nymphs of the cotton mealybug, *P. solenopsis*.

Killing power (as K-value) of *H. vinciguerra* adults was generally higher on *P. solenopsis* nymphs (the mean of K-values was 0.546) in comparison with adults (the mean of K-values was 0.464). The highest K-value was obtained at the predator: prey ratio of 1: 10; where, it reached 1.100 and

1.457 on *P. solenopsis* adults and nymphs, respectively (Figure, 4). K-values decreased in the rest of predator: prey ratios (as increasing the prey numbers) with lowest value at the ratio of 1: 80 on prey adults (k-value = 0.310) and at the ratio of 1: 90 on prey nymphs (k-value = 0.492).

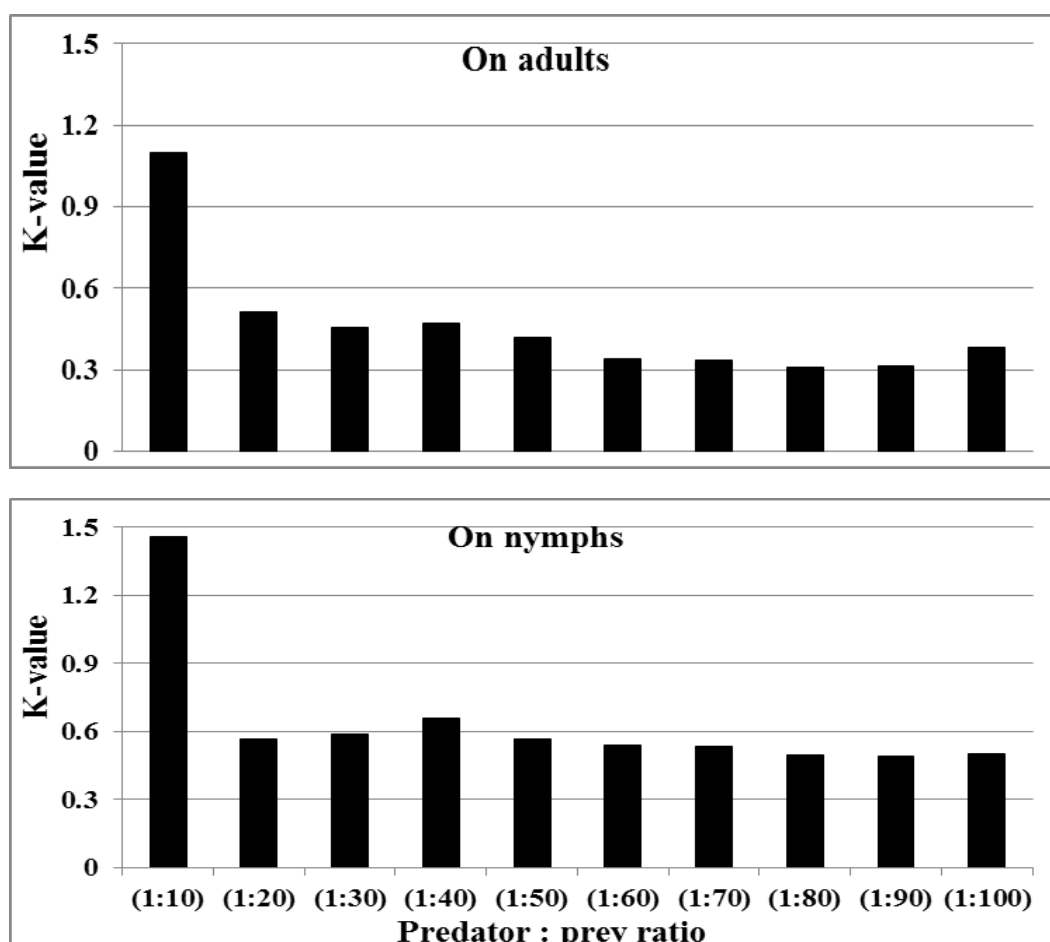


Fig 4: K-value of *H. vinciguerra* (as adults) at different predator: prey ratios on adults and 3rd instar nymphs of the cotton mealybug, *P. solenopsis*.

5. Discussion

The green lacewing, *C. carnea* and coccinellid beetles (*i.e.* the pitchfork lady beetle, *H. vinciguerra*) are potential predators on many insect pests. They have significant potential for commercialization and use against many crop pests in

combination with other insect pest management tactics [16, 27-33]. The efficiency of these predators may be affected by many factors, such as their body size, developmental stage, prey species and its density & stage, climate, chemical cues, plant morphology and heterospecific predation, food scarcity, and

parasitism [15, 16, 25, 29, 33-43]. These studies support the present results; however, both of *C. carnea* and *H. vinciguerra* showed relatively higher searching rates on the nymphs of cotton mealybug, *P. solenopsis* in comparison with prey adults. On contrary, mutual interference of *C. carnea* and *H. vinciguerra* was higher on prey nymphs in comparison with adults.

The present results showed that killing power (as K-value) of both *C. carnea* and *H. vinciguerra* was higher at the predator: prey ratio of 1: 10 and decreased as increasing the prey numbers. Also, Bayoumy & Michaud (2012) [25], Al-Doghairi *et al.* (2014) [16] and Bayoumy *et al.* (2019) [33] reported that increasing the number of predators per arena did not result in a proportional increase in consumption rate due to the effects of mutual interference. Ghanim (2004) [38] and Bayoumy & Ramadan (2018) [44] added that predator consumption and predation efficiency increased with increasing predator density, supporting the inference that high predator densities will increase rates of prey consumption overall, regardless of whether the predator was stressed or not.

According to Bayoumy *et al.* (2019) [33], the decrease in the area of discovery as a function of increasing predator density suggests that mutual interference among predator individuals increased. This is may be attributed to confinement in the experimental arena generating high conspecific encounter rates. The same author cleared that predator aggregation in a specific prey patch will increase negative conspecific confrontations. Thus, mutual interference between individuals of the same species in direct interactions may alter their foraging success [45]. As prey density increases the consumption rates per individual predator decreases [15, 16, 25, 44, 46, 47]. But in the study of Bayoumy *et al.* (2019) [33], the consumption rate per individual predator of both predator species decreased as the available numbers of prey per searching individual decreased. These findings support the present results which explained that k-values were relatively closed at the entire tested predator: prey ratios except that of 1: 10 ratio.

6. Conclusion

Larvae of *C. carnea* were more effective on the nymphs and adults of cotton mealybug, *P. solenopsis* than *H. vinciguerra* adults. On the other hand, the predator *C. carnea* can play an effective role in controlling *P. solenopsis* population when the predator: prey ratio is about 1: 10. Accordingly, in augmentative biological programs of *P. solenopsis* by predators, predator: prey ratio has to be accurately estimated to minimize the negative effects of interference on foraging efficiency.

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